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An approach to decreasing the peak electrical demand in residences

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Abstract

A project to reduce the peak electrical demand by 65% for a new residential housing development in the Desert Southwest portion of the US is described. The period of the peak demand is considered to be 1:00 pm to 7:00 pm local daylight savings time. Four general approaches are being used to accomplish this. One is the use of a very energy conserving design for the buildings. Second, all of the residences have a photovoltaic array on them. Third, some new approaches to demand side management are being developed whereby the utility and the customer interact. Finally, a Battery Energy Storage System (BESS) is being evaluated. Results found to date are summarized in this paper. Predictions for success are given and work remaining is outlined.

Key Words: Peak electrical demand reduction; energy conserving building design; photovoltaic system; and battery energy storage system; automated load control

1. Introduction

In hotter climates, air conditioning can require significantly large amounts of electrical power during higher-temperature periods of the day. This, then, can require utilities to supply expensive electricity, either from old and inefficient plants or from costly purchased grid power. Solutions are sought to decrease demand peaks.

One approach has been the development of time of use (TOU) pricing structures. A study of this approach has shown a reduction of peak usage by 5%.[1] Other approaches have been suggested. [2-6]

It is important to understand the magnitude of the peaking characteristics of the local electric utility. In the Desert Southwest, summer peaks can be a factor of two or more larger than winter peaks.

The project that is the focus of this report is one that came out of a smart grid call for proposals from the US Department of Energy. Personnel from the UNLV Center for Energy Research conceived a

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proposal with Pulte Homes (the world's largest home builder) and NV Energy (the local electric utility). It was decided that a focus on a new housing development would be formulated, and a number of specific thrusts to accomplish a decrease in peak load by 65% would be part of the work plan. The 65% was to be compared to a minimal standard (code-built) home.

Work began immediately after the contract was approved. The focus was on a new Pulte development called Villa Trieste on the west side of Las Vegas that would contain 185 starter homes. An important ingredient of the proposed work was the basic building designs. High levels of energy efficiency would be sought for the homes.

Other aspects considered were renewable energy applications (one of the requirements in the call for proposals) as well as battery storage. The development of a communication system between the utility and the customer for pricing signals and load control would also be a part of it.

2. Development of the Project

The first effort of the project was to determine the plans for the new buildings. It was decided to have five models in this development. All would be starter home sizes for Las Vegas (averaging about 1700 sq. ft. of floor space) on two floors. Pulte Homes has developed a very good reputation not only for building high quality homes but also highly energy conserving homes. In fact they promise buyers about what to expect in terms of monthly energy costs for each of their home models.

The homes would incorporate a variety of energy conservation features. Included was blow-in cellose insulation rather than the glass fiber generally used by builders in this area. Higher SEER air conditioning would be included in addition to tankless water heaters. Also planned was insulating at the roof line. This latter approach allowed the HVAC ducts to be placed in conditioned space. All Energy Star appliances and CFL lighting were used in the homes. No detail was ignored in the quest for cost-effective energy-efficient construction.

A moderately-sized package of PV tiles (about 1.8 kW_p) was selected to be put on each residence. The houses have a variety of orientations, so a roof area closest to south was chosen for the photovoltaic placements. Simulations were performed to evaluate the energy harvest with each direction used for mounting. A paper summarizing the results of this study is being prepared.

Part of the design process of the houses was an analysis to determine the Home Energy Rating Service (HERS) index developed by RESNET (http://www.resnet.us/home1). On this scale, homes that meet the current energy code have a rating of 100. Existing homes, built before the current code was required, generally had higher values of the HERS index. Zero energy homes have a rating of 0. The new homes designed for this project averaged about 45 on the HERS index.

The houses met a number of construction critera for US builders, including Building America, Environments for Living, and, perhaps most impressively, LEED for Homes Platinum certification. Of course the criteria for some of these awards include many qualities beyond energy conservation. So this is a good sign that the development was intelligently designed and built.

The development site was outfitted with a full array of meteorological monitoring instruments. Probably the most important data taken with these are the solar fluxes and the ambient temperature variations.

3. Concern for Time-Dependant Characterizations

Once the homes were designed and construction started, it was important that the research team be prepared for the detailed characterization of the time-varying energy use. While the home designs had undergone extensive HERS evaluations, the net result of that is an indicated year-long energy use. For a focus on peak demand analysis, a different kind of energy analysis had to be performed. The software ENERGY-10™ (http://www.nrel.gov/buildings/energy10.html) was used.

The basic approach to energy use characterization for the houses is the following. All houses have smart meters on them that record the nearly instantaneous energy use continuously as a function of time. This is extremely valuable for characterizing the overall peak performance of the whole development. However, it does not give detailed information that is desired to understand contributions to the total energy use that can take place. So several residences are outfitted with additional energy data monitoring equipment. Particular focus of this information is about the thermostat settings, the energy used by the various aspects of the air conditioning systems, the PV generation details, and several other aspects. Instruments were incorporated into a wireless data gathering system that was designed. One of the many features shown with the detailed monitoring is that the full electrical load of the houses follow very closely the ambient temperature variations.

4. Studies of Peak Reduction Scenarios

With details in hand of the various contributions to the total load, it was then possible to move to the next phase of the analysis. Meteorological data taken simultaneously with house performance data were used with the ENERGY-10™ software to simulate the house energy utilization behavior. If the simulation is sufficiently accurate, it will compare favorably to the acquired experimental data.

One example of this is shown in Figure 1. Here measured energy required for the air conditioning system is compared to predicted air conditioning energy required. Note that actual weather data for the same days were used in the simulation. Clearly the model is showing close agreement with the experimental data.

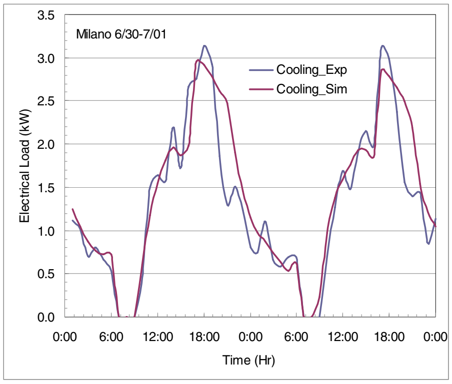

Figure 1. A comparison for the electrical load required for the cooling of one of the houses over a two-day period. The recorded meteorological data for the same days were used in the simulation. Generally very good argreement is demonstrated in this transient data, as well as in the accumulated data totals.

As the close correspondence between the simulations and the measurements was established, the process could move forward. At this point the software becomes extremely useful for performing "what if" kinds of studies. A variety of kinds of effects was assumed to be incorporated into the house operations that would affect its energy use. Not only can the impact on the peak electrical demand be assessed, but it is also the case that the impact on the thermal environment of the house can be estimated.

A set of studies addressed the impact that could be accomplished by active load control. NV Energy has had a program in place for several years called "Cool Share." In this program, customers could enroll voluntarily. The utility would then have the ability to turn off building air conditioning systems for short times in periods of severe demand. If this function can be applied at random times to a large number of buildings with only subsets being curtailed at any one time, the overall load on the system can be reduced accordingly with little impact on the customers. Enrolled customers are given a small credit to their electric bill every time something like this occurred. Several customers in the NV Energy service area are active participants in this program.

The current project has the ability to carry this approach several steps further with embellishments that are being incorporated to the load control strategies. A key element of this is having control of the room thermostats if the customer gives approval. As with the Cool Share program, each "occurrence" would result in a small credit to the customer's account. With thermostat control, precooling of the house could occur (i.e. the house is cooled more during off-peak periods not to be actively cooled as much during on-peak periods). Another scenario is simply to set the thermostat a few degrees (perhaps 2 or 3) higher during peak demand periods (setback). A control system was developed using the ZigBee approach. This approach was selected in agreement between NV Energy personnel and UNLV researchers based upon a number of criteria, including the general openness of the software.

Although many scenarios were examined for the project, including detailed examination of the orientation of the individual PV arrays, only one example will be shown here. This is depicted in Figure 2. In this figure the impact of a variety of the features on the peak electrical demand is shown. Of importance is to determine the transient energy use of a code-built house, and this is shown in blue. Estimated performance of a Villa Trieste home without PV is shown in black. The anticipated decrease in energy use due to the variety of conservation features incorporated into the home is shown. When the PV array's impact on net energy use is shown (in red), an additional decrease in peak energy use is anticipated. However, as is well known from many previous studies, the PV output does not necessarily cover the whole peak period. Hence another element is required. In the situation depicted in the figure, a setback (in green) is considered. This clearly cuts into the peak demand. A variety of setbacks were evaluated for their influence on room temperatures. This is also of concern.

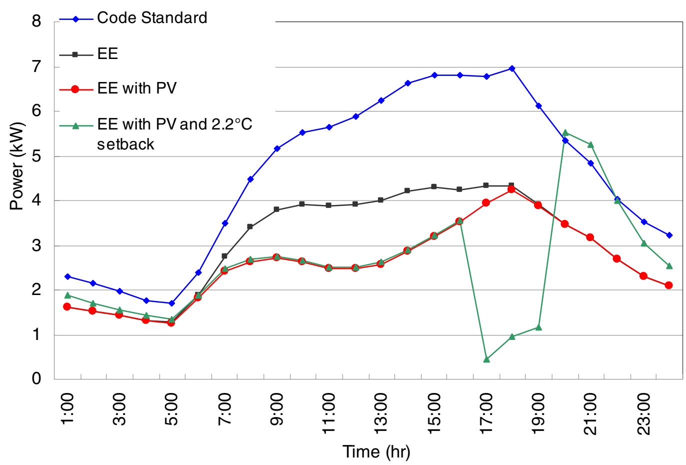

Figure 2. Four scenarios that were examined to see their impact on peak demand variations. The blue line indicates the estimate of the energy use of a code-standard house; the black line indicates what would be achieved considering the Pulte house with only its energy conservation features; the red line demonstrates the impact of adding PV to the energy conserving house; and finally the green line shows what would happen with a 2.2°C setback in addition to the other aspects.

5. The Remaining Work to Do

While the project has developed a great deal of insight on how the target amount of peak electrical reduction might be accomplished for this location, work remains to be completed. As with the results reported above, this could have far reaching applicability. Two of the major issues currently being addressed will be briefly described.

The first of these is the full development of an active communication system between the utility and the resident. This will adapt to the ZigBee development mentioned earlier. It will allow the utility to transmit current-time energy prices to the consumers, whether or not the latter are on a TOU plan. The consumers will have a variety of responses they can make to this information. A large portion of this is embedded in something called the "Intelligent Agent" system that is being developed in this project. One of the ways this will be apparent to the consumer will be the equivalent (not the reality, though) of a large red dial in the home. When the consumer sets this fully one direction, it would mean she/he would like to minimize energy costs as much as physically possible without having to live in an uncomfortable environment. Setting the dial fully the other direction would mean that the consumer has no concern whatsoever about how much energy is being used. Intermediate settings would result in intermediate savings.

Several steps are being pursued in the development of this system. From the UNLV CER side, work is going forward on wrapping the "intelligence" into the Intelligent Agent. For this, both the house and the consumer living habits would be calibrated. Then estimates of the range that variables could fill are programmed into the system. Included are items like thermal comfort ranges, prioritizing less important electrical appliances, the amount of lighting generally preferred, and so forth. The system will have the ability to allow the consumer to react remotely to specific actions as well as to initiate actions of her/his own desire.

Another part of the project that is proceeding but not yet accomplished is the development of an interactive battery energy storage system. This would be charged off-peak, and it would be discharged, if needed, on-peak. This system will be treated as the final action invoked if sufficient decrease in peak is not achieve with the other aspects, including the Intelligent Agent briefly described in the previous paragraph.

When the proposal for the project was submitted, it was thought that a major battery facility could be set up at the substantion level to furnish power to several local developments as might be needed. This option was eliminated early in the first phase of the project for a number of reasons, including costs and other aspects equally as important. So attention has focused on systems of smaller scale ranging from development-sized units to individual home units. An example of the possible impact of a development-sized unit is shown in Figure 3.

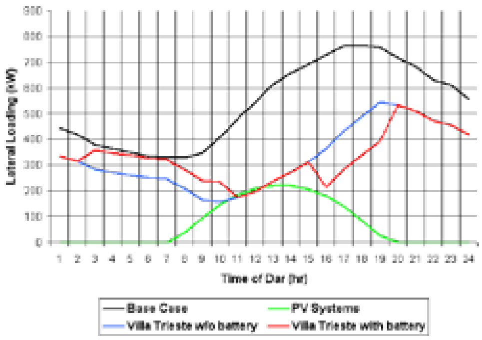

Figure 3. The impact on peak demand is shown as a result of using a 150 kW/600 kWh storage battery system on the Villa Trieste development.

With the variety of interests concerning the three partners in the project: the homebuilder (most interested in minimizing impacts on the customers' living area), the utility (questions about battery ownership and liability of the utility company), and the University (hoping to meet the promised peak reduction), this is a complicated issue.

6. Concluding Comments

1. A project has been conceived and funded to bring down peak electrical demands in the Desert Southwest portion of the US. This is being performed on a new development of 185 single-family, two-story residences. The project team includes a university research center, a homebuilder company, and the local electric utility.
2. Four general approaches are being used for doing this. One involves a highly energy conserving building design, another includes an array of PV tiles on southerly facing roofs, a third is the development of an advanced load control/communication system between the utility and the customer, and fourth is the interfacing of a battery energy storage system that will be charged off-peak and discharged (if needed) on peak.
3. Performance of the house design alone carries the project quite a way toward the peak reduction goal. The PV also assists but does not always cover the defined peak period duration.
4. The battery system could make up the deficit if needed. However, it is preferred that this not be used too heavily because the devices' round trip efficiencies are low.
5. Least quantifiable at this point is the impact that the active communication/advanced load control system with Intelligent Agent might have on the overall peaking situation. It is felt that this will be able to cover the necessary peak reduction without using the battery system.

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